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ORIGINAL ARTICLE

Investigating pressure drop across wire mesh mist eliminators in bubble column

Abdullah A. Al-Dughaither [a], Ahmed A. Ibrahim [b], Waheed A. Al-Masry [b,*]

[a] *SABIC Research and Technology Complex, Riyadh, Saudi Arabia*
[b] *Department of Chemical Engineering, King Saud University, Riyadh, Saudi Arabia*

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Abstract Effects of design parameters on pressure drop across the wire mesh mist eliminators were experimentally investigated in 15 cm bubble column. The pressure drop across the demister pad was evaluated as a function of wide ranges of operating and design parameters. These parameters include: specific surface area (236–868 m^2/m^3), void fraction (97–99%), wire diameter (0.14–0.28 mm), packing density (130–240 kg/m^3), and superficial gas velocity (0.109–0.118 m/s). All demisters were 15 cm in diameter with 10 cm pad thickness, made from 316L stainless steel layered type. Experiments were carried out using air–water system at ambient temperature and atmospheric pressure. The measurements of the pressure drop were done using a U-tube manometer device. The pressure drop across the demister pad is a combination of dry and wet pressure drops. In this work, the experimental investigations showed that the dry pressure drop is nil. The wet pressure drop was found to increase with increasing the demister specific surface area, packing density, and superficial gas velocity. In contrast, it was found to increase with decreasing the demister void fraction and wire diameter. The pressure drop is correlated empirically as a function of the design parameters. A good agreement was obtained between the measured values and the correlation predictions with ±15% accuracy.

1. Introduction

In many operations in the petrochemical, oil production and thermal desalination plants, it is frequently necessary to remove fine droplets of liquid from process and waste gas or vapor streams. Liquid separation is required to recover valuable products, improve product purity, increase throughput capacity, protect down stream equipment from corrosive or scaling liquids, avoid undesired reactions in the reactors overhead lines, and to improve emissions control. Mist eliminators are devices that can remove entrained liquid from gas flow effectively. As the rate of a spontaneous separation process is often

* Corresponding author. Tel.: +966504184158.
E-mail addresses: degether@sabic.com (A.A. Al-Dughaither), aidi@ksu.edu.sa (A.A. Ibrahim), walmasry@ksu.edu.sa (W.A. Al-Masry).

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Nomenclature

A	Bubble column cross sectional area (m^2)	*Greek Letters*	
A_s	Specific surface area (m^2/m^3)	Δp	Pressure drop across the demister (cm H_2O)
D_w	Demister wire diameter (mm)	Δp_{dry}	Dry Pressure drop (cm H_2O)
f	Friction factor (–)	ε	Void fraction (–)
H	Thickness of the demister mesh pad (m)	ρ_g	Gas density (kg/m^3)
Q_g	Volumetric flow rate (m^3/s)	ρ_l	Liquid density (kg/m^3)
V_g	Superficial gas velocity (m/s)	ρ_p	Packing Density (kg/m^3)
K	Velocity constant (depending on application) (m/s)	μ_g	Gas Viscosity (kg/ms)
g	Gravitational constant (9.81 m/s^2) (m/s^2)		
Re	Reynold's Number (–)		

economically and operatively desirable, mist eliminators are generally employed to accelerate this step and to increase throughput capacity. For example, in thermal desalinations plants, the droplets must be removed before vapor condensation over condenser tubes. If the mist eliminator doesn't separate efficiently the entrained water droplets, reduction of distilled water quality and formation of scale on the outer surface of the condenser tubes occurs. The last effect is very harmful because it reduces the heat transfer coefficient and enhances the corrosion of the tube material (Souders and Brown, 1934; Fabian and Cusack, 1993; Fabian and Hennessy, 1993).

Another example is the two phase bubble column reactors. Bubble columns have been widely used in industry because of their simple construction and operation. Important applications include hydrogenation, oxidation, polymerization, Fischer–Tropsch synthesis, ozonolysis, carbonylation, carboxylation, alkylation reactions as well as for petroleum processes. Other important application area of bubble columns is their use as bioreactors in which microorganisms are utilized in order to produce industrially valuable products, such as enzymes, proteins, antibiotics, etc. In the bubble column, the gas is introduced in the form of bubbles into a pool of liquid via a distributor. The mass transfer and hence the reaction takes place between the gas bubbles and the liquid. The gas stream leaving the liquid pool entrains droplets of liquid with it, which must be removed before it exits the reactor. Failure to do so will cause the reaction to continue in the exit streamlines. In polymerization reactions for example, the entrainment will cause plugging of the exit streams and overhead lines.

Many mist eliminators have been developed with various efficiency and cost. Mist eliminators belong to one of the ollowing groups: settling tank, fiber filtering candles, electrostatic precipitators, cyclones, impingement van separators and wire mesh. Each of these devices operates under different principle and is applied for the removal of the droplets with a specific size range and effective separation performance. When selecting a mist eliminator, careful considerations should be given to performance parameters and one must weigh several important factors so as to ensure a cost effective installation (Bell and Strauss, 1973; York, 1954). The important performance parameters of liquid separators are capacity, pressure drop, droplet removal efficiency and plugging tendency. These parameters are all interrelated and should be considered together when comparing the performance of alternative mist eliminators (Brunazzi and Paglianti, 2001). Operating pressure is expressible as an energy expense so low pressure drop is required. Pressure drop is primarily a function of superficial gas velocity, mist loading and the mist's physical properties, such as density and viscosity. If the entrained droplets contain solids, susceptibility of the separator to plugging by solids shall be considered. Additionally, it is needed to evaluate whether the mist eliminator can be installed inside the existing equipment, or if needs a standalone vessel instead (easy of manufacture and installation are preferred). Concerning the material of construction, the availability of materials that are compatible with the process is also an important factor. The medium and structural support materials must be durable enough to withstand process conditions and provide an acceptable service life. Table 1 shows equipment selection according to some performance parameters.

The knitted wire mesh mist eliminator, commonly specified as the "demister", is one of these devices which has a widespread application in many industrial plants. It is a simple porous blanket of metal or plastic wire that retains the liquid droplet. It has gained extensive industrial recognition as low pressure drop, high separation efficiency, reasonable capital cost, minimum tendency for flooding, high capacity, and small size. It probably outnumbers all other types of mist eliminators combined specially in petrochemical industries. The wire mesh entrainment separator is installed without difficulty in process equipments, such as scrubbers, evaporators and distillation columns. Although knitted wire mesh has been used by industry for broad ranges of entrainment elimination operations, the volume of fundamental work published regarding their performance characteristics is scant. The work of Satsangee (Satsangee, 1948) was concerned primarily with wire mesh as column packing and contacting media and not specifically entrainment elimination. The detailed investigation studied wire mesh as an entrainment separator in an evaporator handling salt solution and defined the efficiency, pressure drop, and capacity of knitted wire structure.

As generally used, knitted wire mesh mist eliminator consists of a bed, usually 10.16–15.24 cm deep, of fine diameter wires interlocked by a knitting to form a wire mesh pad with a high free volume, usually between 97% and 99%. The separation process in the wire mesh mist eliminator includes three steps; first 'inertia impaction' of the liquid droplet on the surface of wire. The way in which the mist wets the collecting medium determines whether the liquid will coalesce in a drop wise -or film wise- fashion; a characteristic that influences operating pressure drop (Plant and Fairs, 1963). Mists that coalesce into droplets lead to lower pressure drops. The second

Table 1 Equipment selection versus mist particle size (Ziebold and May 2000).

Style	Brownian Fiber beds	Impaction Fiber beds	Mesh pads	Vane separator
Collecting fiber diameter (μm)	8–10	10–40	100–300	> 300
Bed velocity (m/s)	0.05–0.25	1.25–2.5	2–4	2.5–5.0
Pressure drop (mm H_2O)	100–450	100–250	10–75	3–25
Particle size collected (μm)	< 0.1–3	1–3	2–20	> 20

stage is the coalescence of the droplet impinging on the surface of the wires. In the third step, droplet detach from the pad. The primary factors affecting demister droplet removal are gas velocity, surface area, free volume and hence, diameter of fibers used in mesh knitting. The thickness or depth of a demister is also a very important parameter. Removal efficiency of the mist eliminator is increased by having a thicker mesh pad. However, increasing demister thickness causes a greater reduction in pressure. Adding to this, the removal is exponentially related to the thickness while pressure is linearly related to thickness, (Capps, 1994; Payley, 1973; Robison, 2003).

2. Prediction of pressure drop

The pressure drop of knitted wire mesh droplet separators is very low due to the large free volumes even at higher velocities. It rises almost proportional with the thickness of the package and acts nearly proportional to its density (with the same wire diameter and knitted wire mesh specification). Liquid load, viscosity, wetting behavior of the liquid, as well as the contamination level of the gas stream (solid particles) have a strong influence on the pressure drop.

The pressure drop through the wire-mesh demister is often small enough to be neglected. The effect of low pressure drop becomes more significant in mesh design for vacuum distillation and for equipment where the prime mover is a blower or fan. Pressure drop assumes importance in the existing blower driven system since an increase in back pressure is accompanied by a reduction in delivered gas volume which increases the power consumption (York and Popple, 1963; Feord et al., 1993).

The pressure drop through a wire mesh mist eliminator is a combination of dry pressure drop due to gas flow only, plus the wet pressure drop due to liquid holdup. When a certain superficial gas velocity is exceeded, the liquid builds up in the mesh with large increase in the pressure drop. At this point, the flooding point is considered at maximum velocity. General design methods are based on the computation of designed superficial gas velocity from which the cross-sectional area of the pad is determined. The lower limit of the velocity is often set at 30% of the design velocity to maintain reasonable efficiency. The upper limit is governed by the need to prevent re-entrainment of liquid droplets from the downstream face of wire mesh device. The maximum velocity is computed from a modified Souder–Brown equation (Knit wire Products- Knitted mesh mist eliminator – Technical Journal, world class reliability, quality and service, 2003):

$$V_{\mathrm{gmax}} = K\sqrt{\frac{\rho_{\mathrm{l}} - \rho_{\mathrm{g}}}{\rho_{\mathrm{g}}}} \tag{1}$$

where ρ_l and ρ_g are, respectively, the density of the liquid and the gas phases. The constant K depends on several system factors including liquid viscosity, surface tension, entrainment loading, content of dissolved and suspended solids, operating pressure, mesh structure and de-entrainment height (Carpenter and Othmer, 1955). The values of K are experimentally determined by vendors, (KOCH-OTTO YORK, 2002; ACS separation and mass transfer products, USA, 2004; Knit wire Products-Knitted mesh mist eliminator, 2003). For industrial applications, a value of $K = 0.107$ m/sec has been using over 40 years as a standard guideline for calculations based on KOCH-OTTO YORK styles; (KOCH-OTTO YORK, 2002; Ettouney, 2005).

For calculating the dry pressure drop, Carman (Carman, 1937) developed a correlation for flow through packed beds. This study has been used by York and Popple (York and Popple, June, 1963) to predict the dry pressure drop (in Ibf/ft^2) through the wire mesh demister which has been expressed as:

$$\Delta p_{\mathrm{dry}} = \frac{fHA_{\mathrm{s}}\rho_{\mathrm{g}}V_{\mathrm{g}}^2}{g\varepsilon^3} \tag{2}$$

where f is the Friction factor, H is the thickness of mesh pad, A_s is the specific surface area of the demister, V_g is the superficial gas velocity, ρ_g is the gas density, g is the gravitational force and ε is the void fraction. The friction factor is a function of Reynolds number:

$$Re = \frac{\rho_g V_g}{A_s \mu} \tag{3}$$

The friction factor can be determined based on Reynolds number from Fig. 1.

The second work on dry mesh pad pressure drop was presented by Saemundson (Helsr and Svendsen, 2007). He used the expression for turbulent pressure drop (in Pa) in a channel as a starting point for his correlation. He then introduced the wire mesh hydraulic diameter and corrected the velocity by dividing it with the porosity as shown in the following expression:

$$\Delta p_{\mathrm{dry}} = \frac{f H\rho_{\mathrm{g}} V_{\mathrm{g}}^2}{2R_{\mathrm{h}}\, \varepsilon^2} \tag{4}$$

where R_h is the wire mesh hydraulic radius and f is a friction factor given by the following relations:

$$R_{\mathrm{h}} = \frac{\varepsilon D_{\mathrm{w}}}{4(1-\varepsilon)} \tag{5}$$

And

$$f = \frac{34}{Re} + \frac{1.4}{Re^{0.2}} \tag{6}$$

In Eq. (6), Re is the Reynolds number with the hydraulic diameter used as the length scale which can be determined as:

$$Re = \frac{D_{\mathrm{w}}\rho_{\mathrm{g}}V_{\mathrm{g}}}{(1-\varepsilon)\mu_{\mathrm{g}}} \tag{7}$$

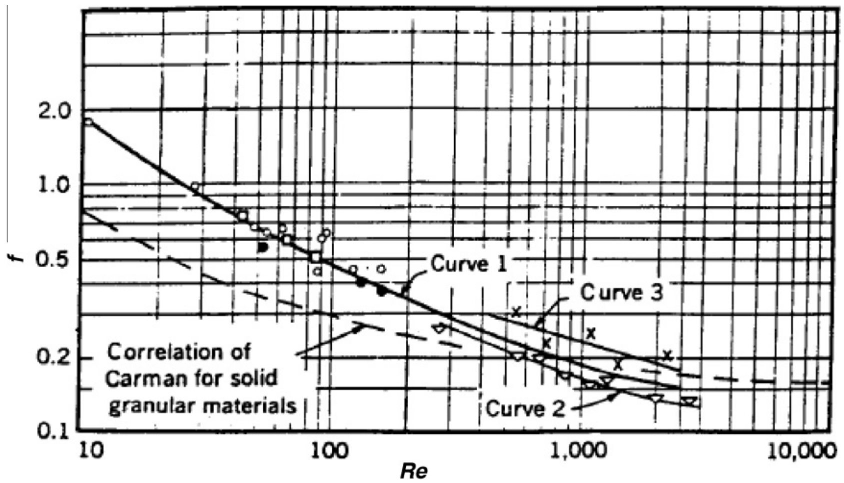

Figure 1 Friction factor, *f*, versus Reynolds number, *Re*, for dry wire mesh demister (York and Popple, June, 1963).

In normal operation of a demister only bottom part (about an inch) of the mesh is witted (Bradie and Dickson, 1969). During this operation, certain pressure drop is created. This is called "wet pressure drop" which is function of liquid loading as well as the demister geometry. Bradie and Dickson (Bradie and Dickson, 1969) discussed the factors governing the wire mesh demister, and in particular with their application to entrainment removal in pool boiling systems. They derived an equation to predict the wet pressure drop gradient (in Ibf/ft^2) with the change of the wire mesh demister thickness as follows:

$$\frac{dP}{dH} = \rho_g + \tau_{lg} \frac{A_s}{\varepsilon x^{1/2}} \tag{8}$$

where τ_{lg} is the shear stress (lb/ft^2) between liquid and gas and x is the dryness fraction in the demister that can be expressed as:

$$x = \frac{\textit{Volume occupied by vapor}}{\textit{Volume of demister} - \textit{Volume occupied by wires}} \tag{9}$$

Bradie and Dickson measured the wet pressure drop for a series of demisters installed in a small 140 mm diameter wind tunnel. The tested demisters included the layered and spiral-wound configurations. They reported that the results could be used in the design of the demister although there are still some discrepancies as to the effect of reducing the wire diameter, and the effect between spiral-wound and wire mesh. All the experimental results were taken for air–water at atmospheric pressure and ambient temperature. No attempt has been made to use fluids with different properties or to operate the system at other conditions.

In the open literature, there are some studies to predict the wet pressure drop empirically. However, those empirical correlations are considered only at specific system and certain ranges of the experimental variables. Example can be found in the work by El-Dessouky and others (El-Dessouky et al., 2000) where they derived an empirical correlation to predict the wet pressure drop across the wire mesh demister as a function of packing density (ρ_p), wire diameter (D_w), and gas velocity (V_g). However, their correlation felt short to describe the effect of specific surface area and void fraction. The system they used is typical multi stage flash (MSF) desalination units. Their ranges of the experimental variables were V_g (0.98–7.5 m/s), ρ_p (80–208 kg/m^3), and D_w (0.2–0.32 mm).

In some occasions, however, the application of bubble columns requires lower gas velocity (<0.2 m/s) which could make the above relations not reliable for bubble column applications. To the best of our knowledge, there is no study available in the open literature that deals with the application of the wire mesh mist eliminator in bubble column.In view of the previous discussion the following conclusions can be drawn:

1 We believe that the open research on the pressure drop across the wire mesh mist eliminators is very limited despite the broad range of entrainment removal applications.
2 The available theoretical or empirical models that describe the pressure drop across the wire mesh mist eliminators are not adequate for implementing to the industrial units. The case of bubble column, however, is very extreme where there is no model to predict the pressure drop across this type of demister.

The present investigation reports the results of experimental work using a knitted wire mesh separator as an entrainment eliminator in bubble column. Various types of wire-mesh separators that are different in geometrical specifications are employed. The main objectives of this study are:

1 To investigate the design characteristics those affect the pressure drop across the wire mesh demister employing a bubble column.
2 To develop a correlation for predicting pressure drop across the demister inside bubble columns. This correlation is established for the pressure drop as function of specific surface area, void fraction, wire diameter, packing density, and superficial gas velocity.

3. Experimental apparatus and procedure

The experimental setup is designed and built at the Department of Chemical Engineering of King Saud University. The experimental work is performed in 15 cm diameter bubble column which is fabricated from galvanized carbon steel. The

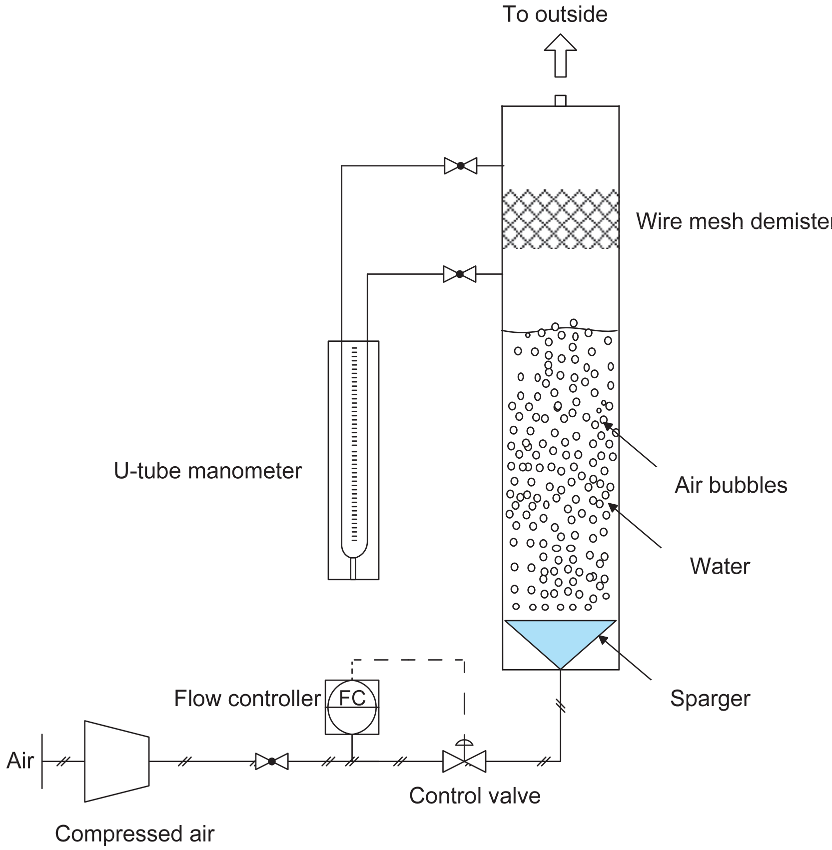

Figure 2 Experimental test apparatus.

upper flange is made of Plexiglas material. The experimental apparatus is schematically sketched in Fig. 2 that includes the system components. The column is equipped with a U-tube manometer to measure the differential pressure across the demister. The high side of the manometer is connected at the upstream of the demister while low side is fixed to the downstream of the demister. Air flow rate is controlled using Omega Engineering Volumetric Flow Controller (Model No. FMA-2611). The flow set point is set by the digital readout device and the required flow is maintained accordingly. Air flows via perforated plate (sparger) through water pool in bubble column and detaches from the liquid surface towards the demister. This area is called disengagement zone which is fixed at 14 cm. The water droplets were carried over by air stream flowing towards the demister. Part of the large size droplets return back to the water pool as a result of gravity and most of the droplets continue flowing up towards the demister. The test demisters are supplied by RHODIUS GmbH. They are varied in geometric characteristics as shown in Table 2. All demisters are 15 cm diameter, 0.1 m pad thickness and made from Stainless Steal 316L without supporting grid. All experiments were carried out at ambient temperature and atmospheric pressure (T = 25 °C and P = 1 atm).

Superficial gas velocities are calculated using:

$$V_g = \frac{Q_g}{A} \tag{10}$$

where Q_g (in m^3/s) is the volumetric flow rate at atmospheric pressure and ambient temperature. A is the cross sectional area of the column which is fixed at 0.018 m^2.

The pressure drop (ΔP) is calculated directly by taking the height difference (cm) between two sides of the U-tube

Table 2 Geometric characteristics of the test demisters.

Type	Wire Diameter (mm)	Packing Density (kg/m^3)	Specific Surface Area (m^2/m^3)	Void Fraction(%)
RHO-80-SS-0.28	0.28	80	145	99
RHO-110-SS-0.28	0.28	110	200	98.6
RHO-130-SS-0.28	0.28	130	236	98.3
RHO-145-SS-0.28	0.28	145	265	98.1
RHO-175-SS-0.28	0.28	175	320	97.8
RHO-240-SS-0.28	0.28	240	435	97
RHO-130-SS-0.14	0.14	130	472	98.3
RHO-240-SS-0.14	0.14	240	868	97

manometer. This value will give the differential pressure across the demister in cm H_2O.

Demisters are usually specified by means of their geometrical specifications like specific surface area (A_s), void fraction (ε), wire diameter (D_w), and packing density (ρ_p). These parameters are defined as:

$$A_s = \frac{Surface\ area\ of\ wires}{Volume\ of\ demisters} \tag{11}$$

$$\rho_p = \frac{Mass\ of\ wires}{Volume\ of\ demisters} \tag{12}$$

And

$$\varepsilon = 1 - \frac{Volume\ occupied\ by\ wires}{Volueme\ of\ demisters} \tag{13}$$

4. Results and discussion

In this investigation, a series of hydrodynamic experiments are performed to study the effect of the design parameters on the pressure drop across wire mesh mist eliminator in a bubble column. Eight experiments for dry demisters (without liquid holdup) and another eight for wet demisters were conducted using eight demisters at different design parameters. Those parameters include specific surface area (A_s), void fraction (ε), wire diameter (D_w), packing density (ρ_p), and superficial gas velocity (V_g). The total pressure drop across the wire mesh demister is the summation of the pressure drop across the dry demister plus the additional pressure drop contributed by the liquid load within the mesh. The overall experiments indicate that over gas velocity range of 0.109–0.118 m/s, there is no pressure drop across the dry demisters in bubble column (without liquid inventory). On the other hand, there were clear effects of the design parameters on wet pressure drop.

4.1. Effect of specific surface area

Fig. 3 elucidates the obtained pressure drop as function of superficial gas velocity at different specific surface areas for two different wire diameter demisters. These are 145, 200, 265, and 435 m^2/m^3 for 0.28 mm wire diameter; and 472 and 868 m^2/m^3 for 0.14 mm wire diameter. As it can be seen, all curves show similar trends where the pressure drop increases with the increase of the specific surface area. As defined by Eq. (11), the specific surface area represents the ratio of the total surface area of the wires to the total volume of the demister. The increase of the surface area is associated with the increase of the packing density. As a result, the number of the entrained droplets that reach the wires and the amount of captured droplets increases at larger packing density. Due to that, the liquid begins to accumulate or load the demister and this progressively decreases the free space for the gas flow. This fact can be used to explain the steady increase of the pressure drop with the increase of the demister surface area. The maximum pressure drop obtained for 0.28 mm wire diameter demisters was 17.7 cm H_2O at 435 m^2/m^3 surface area and 0.118 m/s superficial gas velocity. Alternatively, the minimum pressure drop obtained was 3.8 cm H_2O at the conditions of 145 m^2/m^3 surface area and 0.109 m/s superficial gas velocity. For 0.14 mm wire diameter demisters, the maximum pressure drop acquired was 20.4 cm H_2O at 868 m^2/m^3 surface area and 0.118 m/s superficial gas velocity. However, the lowest pressure drop recorded was 10 at the conditions of 472 m^2/m^3 surface area and 0.109 m/s superficial gas velocity.

4.2. Effect of void fraction

Void fraction (ε) represents the ratio of the volume of the demister interstices to its total volume. The interstices can be quantified as the subtraction of the total demister volume to the volume occupied by the wires. The void fractions of demisters with 0.28 mm wire diameter are 97%, 97.8%, 98.3% and 99% while 0.14 mm wire diameter demisters have 97% and 98.3% void fractions. The pressure drop is plotted for each void fraction against gas velocity as shown in Fig. 4. It is observed that the measured pressure drop increases as the void fraction decreases. This phenomenon happened due to fact that as volume of vacancies decreases, the free space for the gas flow decreases and results in rapid increase in the flow resistance. This will lead demister to be loaded by liquid (liquid holdup) which will progressively increase the pressure drop. It is noticed that for 0.28 mm wire diameter the pressure drop trends for 97%, 97.8% and 98.3% void fractions are close to each other rather than 99% trend. Nevertheless, for 0.14 mm wire diameter, the difference between the recorded pressure drop trends for 97% and 98.3% is clearly observed. The maximum pressure drop obtained for 0.28 mm wire diameter demisters was 17.6 cm H_2O for both of 97% and 97.8% void fraction at 0.118 m/s superficial gas velocity. For 0.14 mm wire diameter, however, the maximum pressure drop was 20.4 cm H_2O at 97% void fraction and 0.118 m/s superficial gas velocity. The minimum pressure drop found for 0.28 mm wire diameter demisters was 3.8 at the conditions of 99% void fraction and 0.109 m/s superficial gas velocity. Alternatively, for 0.14 mm wire diameters demisters, the lowest pressure drop obtained was 10% at 98.3% void fraction and 0.109 m/s superficial gas velocity.

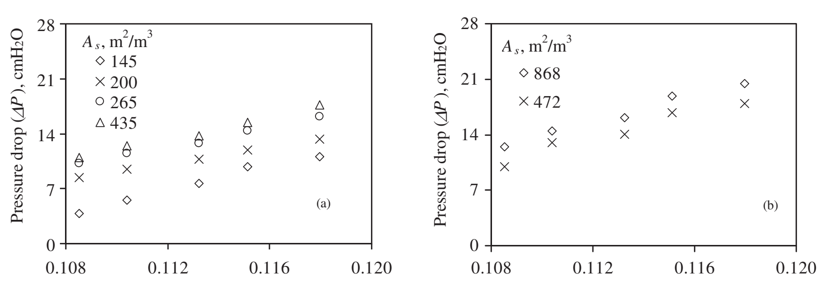

Figure 3 Effect of surface area on the pressure drop at different gas velocities: (a) D_w = 0.28 mm; (b) D_w = 0.14 mm.

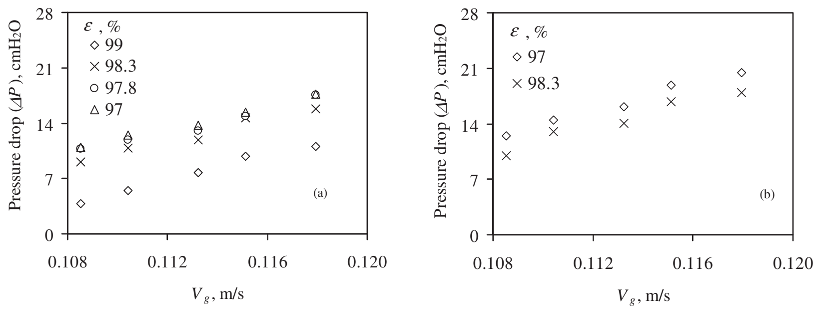

Figure 4 Effect of void fraction on the pressure drop at different gas velocities: (a) $D_w = 0.28$ mm; (b) $D_w = 0.14$ mm.

4.3. Effect of wire diameter

The effect of the wire mesh diameter on the pressure drop with the increase of superficial gas velocity is plotted in Fig. 5 for tow different packing densities (130 and 240 kg/m^3). For each packing density, two different wire diameter demisters are utilized (0.14 and 0.28 mm). Fig. 5 illustrates that the pressure drop is inversely related to the wire size. This is caused by the increase of the wire surface area for smaller wire diameter (e.g. for $\rho_p = 240$ kg/m^3, $A_s = 868$ m^2/m^3 for 0.14 mm D_w but for 0.28 mm, $A_s = 435$ m^2/m^3). Therefore, the thinner wires provide dense packing that can trap the entrained droplets by capillary action between the wires. Capillarity action can be explained by considering the effects of two opposing forces: adhesion, the attractive (or repulsive) force between the molecules of the liquid droplets and those of the wire surface, and cohesion, the attractive force between the molecules of the liquid. Adhesion causes water to wet the demister wires and thus causes the water's surface to rise. If there were no forces acting in opposition, the water would creep higher and higher on the demister wires and eventually overload the demister. El-Dessouky et. al. came across the same finding whereas the pressure drop increases as the wire diameter is reduced (El-Dessouky et al., 2000). Although, the results show good performance of demisters with smaller wires; on the other hand, use of larger diameter wire is necessary to facilitate demister washing and cleaning. Also, the use of larger diameter wire gives adequate mechanical strength and operational stability. Carpenter and Othmer (Carpenter and Othmer, 1955) emphasized that the reduction in the wire diameter would provide the most effective improvement for capturing the smaller particles, but the physical properties for the material used in making the wire and fabricating it in a machine will control the extent to which a reduction in wire diameter becomes possible or practical. The recorded data displays that the difference for the measured pressure drops for each demister at the same superficial gas velocity are comparable. The maximum difference between two pressure drops was 3.5 cm H_2O at the same parameters (240 kg/m^3 packing density and 0.115 m/s superficial gas velocity). The minimum difference for the measured pressure drop was 0.9 cm H_2O at the conditions of 130 kg/m^3 density and 0.109 m/s superficial gas velocity. The average difference was about 2.5 cm H_2O pressure drop.

4.4. Effect of packing density

Variations in the pressure drop at difference packing densities are shown in Fig. 6. As clearly seen, the pressure drop rises with the increase of the packing density. The gas velocity inside the demister is changed as a result of variations in the system operating parameters or due to the holdup of the liquid phase. As the liquid holdup is progressively increasing, the free space area available for the gas flow decreases and results in rapid increase in the flow resistance. The liquid holdup can be either static or dynamic. Capillary action causes the static holdup and occurs at high retention of the liquid within the demister pad; Langmuir et al., 1946; Chotalal, 2004; El-Dessouky et al., 2000. The dynamic holdup takes place, as the settling velocity of the falling droplets becomes lower than the upward velocity. Six different demisters of 0.28 mm wire diameter were tested at different packing densities. These are 80, 110, 130, 145, 175 and 240 kg/m^3. It is interesting to note that the measured pressure drops trends for 130, 145, 175 and 240 kg/m^3 packing densities demisters are close to each other. However, little more difference is observed for 80 and 110 kg/m^3 demisters. The maximum pressure drop recorded was 17.7 cm H_2O

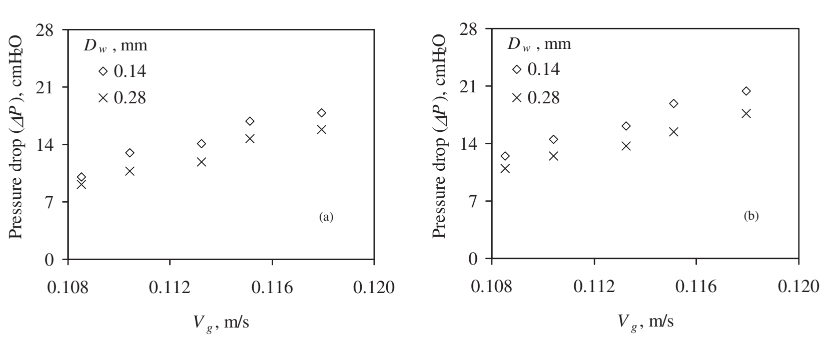

Figure 5 Effect of wire diameter on the pressure drop at different gas velocities: (a) $\rho_p = 130$ kg/m3; (b) $\rho_p = 240$ kg/m3.

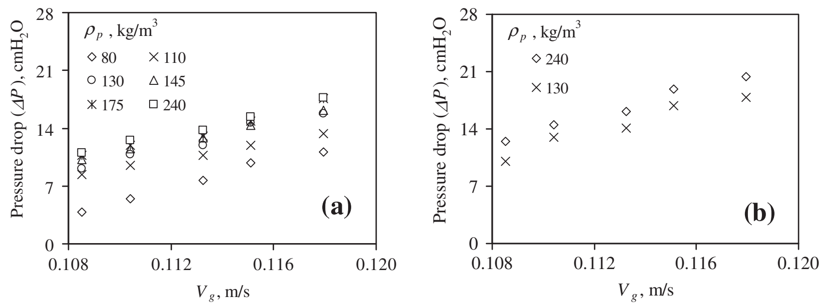

Figure 6 Effect of packing density on the pressure drop at different gas velocities: (a) $D_w = 0.28$ mm; (b) $D_w = 0.14$ mm.

for both of 175 and 240 kg/m^3 packing density at 0.118 m/s superficial gas velocity. On the other hand, the minimum pressure drop gained was 3.8 cm H_2O at the conditions of 80 kg/m^3 packing density and 0.109 m/s superficial gas velocity. For 0.14 mm wire diameter demisters, two packing densities (130 and 240 kg/m^3) were utilized to compare their pressure drops. The highest pressure drop measured was 20.4 cm H_2O as depicted in Fig. 6b at the conditions of 240 kg/m^3 packing density and 0.118 m/s superficial gas velocity. Whereas, the lowest pressure drop obtained was 10 cm H_2O at 240 kg/m^3 packing density and 0.109 m/s superficial gas velocity. It is interesting to observe that for both wire diameters, the effect of the packing density on the pressure drop is obvious at higher superficial gas velocity.

4.5. Effect of Superficial Gas Velocity

The previous figures (Fig. 3–6) illustrate the pressure drop across the demister as a function of superficial gas velocity in m/s. The overall experimental results for different demister design parameters display that the pressure drop shows augmentation as the superficial gas velocity is increased. For low gas velocities, the smaller droplets are entrained with the gas through the disengagement zone till crossing the demister, (Brunazzi and Paglianti, 2000). However, the larger droplets will settle so the liquid holdup in the demister will be less. As the velocity rises, the upward force created by the droplets carried with gas flow outweighs the gravitational force and it tends to go up. This will lead to the increase of the liquid holdup in the demister. As the liquid holdup increases, the free space area available for the gas flow decreases that will cause restriction in the flow and thus increases the pressure drop. The largest pressure obtained was 20.4 cm H_2O at 240 kg/m^3 packing density, 0.14 mm wire diameter, 97% void fraction, 868 m^2/m^3 surface area and 0.118 m/s superficial gas velocity. On the other hand, the minimum pressure drop measured was 3.8 cm H_2O at the conditions of 80 kg/m^3 packing density, 0.28 mm wire diameter, 99% void fraction, 145 m^2/m^3 surface area and 0.109 m/s superficial gas velocity. El-Dessouky et al (El-Dessouky et al., 2000) acquire the same observation where as the gas velocity increased, the pressure drop is steadily raised. But at higher velocities at a certain point, the pressure drop increases steeply even with slight increase of the gas velocity. This point is called Loading Point. Above this point, the liquid begins to accumulate or load the demister progressively causing the decrease of the volume of interstices for gas flow. In this region, the pressure drop increases faster with the increase in the gas velocity. For the present study at 0.14 mm wire diameter, the same observations are noticed. For example, in Fig. 6b the pressure drop varies linearly with the gas velocity up to 0.113 m/s. Above this point, the pressure rises faster with the increase of the superficial gas velocity. This could be named as Loading Point.

5. Correlation of the experimental data

The pressure drop is not easily calculated as it depends on the friction drag of the dry wires, coalesced liquid film, liquid hold up in the wet wires and gas velocity (Knit wire Products, 2003; Monat et al., 1986; Brunazzi et al., 1998). In this work, the pressure drop across the dry demister is neglected since it is nil in all cases. In contrast, an empirical correlation is produced for predicting the wet pressure drop as a function of the main design parameters of the wire mesh mist eliminator in bubble column. These include the surface area (A_s), void fraction (ε), wire diameter (D_w), packing density (ρ_p), and superficial gas velocity (V_g). These correlations are obtained based on 15 cm bubble column diameter and SS wire mesh demister of 15 cm diameter and 0.1 m pad thickness at ambient conditions (T = 25 °C and P = 1 atm). Taking a regression fitting of the experimental data gives the following empirical correlation:

$$\Delta P = 1.0766(A_s)^{0.092}(\varepsilon)^{-0.102}(D_w \times 10^{-3})^{-0.215}(\rho_p)^{0.408}\left(\frac{V_g}{0.113}\right)^{5.328} \quad (14)$$

The considered ranges of the experimental variables D_w(0.14–0.28 mm), ρ_p (130–240 kg/m^3), ε97–99%), A_s (236–868 m^2/m^3), and V_g (0.109–0.118 m/s). Eq. (14) is inline with the experimental observation data where the pressure drop is proportional to the increase of surface area, packing density, and superficial gas velocity. On the other hand, the pressure

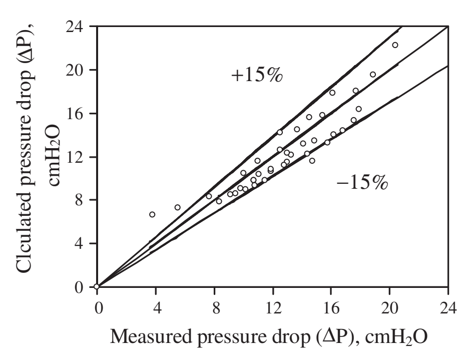

Figure 7 Parity plot for the calculated pressure drop.

drop is reduced with the increase of void fraction and wire diameter. However, the effect of surface area, void fraction and wire diameter are minor compared to effect of packing density and superficial gas velocity. The comparison between the obtained pressure drop data and the calculated values using the developed correlation is shown in Fig. 7. This figure demonstrates clearly that the correlation can be used to evaluate the pressure drop with an accuracy of ± 15%.

6. Conclusions

The available theoretical models developed for the pressure drop across the wire mesh demister are not adequate to apply to bubble columns. Hence, the current study gained more emphasis to understand the performance of the wire mesh demister in term of pressure drop. In this work, the experimental investigations showed that the dry pressure drop is nil. Conversely, the wet pressure drop augments steadily with the increase of the demister specific surface area and packing density and becomes more pronounced at higher superficial gas velocity. In contrast, the pressure drop reduced as the void fraction is increased especially for smaller wire diameter demisters. The same inverse relation is observed for the case of wire diameter. The recorded data displayed that difference between two measured pressure drops at the same superficial gas velocity is comparable. The pressure drop for the wet demisters increased linearly with the increase of the superficial gas velocity up to the loading point, thereafter; the rate of the increase becomes higher. The obtained empirical correlation gives sound model for predicting the wet pressure drop across the wire mesh demister with acceptable accuracy (± 15%).

References

Bell, C.G., Strauss, W., 1973. Effectiveness of vertical mist eliminators in a cross flow Scrubber. Journal of the air Pollution Control Association 23, 967–969.

Bradie, J.K., Dickson, A.N., 1969. Removal of entrained liquid droplet by wire-mesh demisters. Proc. Instn. Mech. Eng. 184, 195–203.

Brunazzi, E., Paglianti, A., 2000. Design of complex wire mesh mist eliminators. AIChE. J. 46, 1131–1137.

Brunazzi, E., Paglianti, A., 2001. Conventional and complex knitted mesh mist eliminators. Chem. Eng. Tech. 24, 1199–1204.

Brunazzi, E., Paglianti, A., 1998. Design of wire mesh mist eliminators. AIChE. J. 44, 505–512.

Capps, W., 1994. Properly specify wire mesh mist eliminators. Chem. Eng. Prog., 49–55.

Carman, P.C., 1937. Fluid flow through granular beds. Chemical Engineering Research and Design 15a, 150–166.

Carpenter, C.L., Othmer, D.F., 1955. Entrainment removal by a wire mesh separators. AIChE. J. 1, 549–557.

Chotalal, S., 2004. ‘‘Fiber bed mist eliminator’’, US Patent No. WO 2004108251.

El-Dessouky, H., Al-Atiqi, I., Ettouney, H., Al-Deffeeri, N., 2000. ‘‘Performance of wire mesh mist eliminator’’, Chem. Eng & Process. 39, 129–139.

Ettouney, H., 2005. Brine Entrainment in Multistage Flash Desalination. Desalination 182, 87–97.

Fabian, P., Cusack, R., bian and Cusack 1993. Demystifying the selection of mist eliminators Pat I: the basics. Chem. Eng. 11, 148–156.

Fabian, P., Hennessy, P., 1993. Demystifying the selection of mist eliminators Pat II: the applications. Chem. Eng. 11, 106–111.

Feord, D., Wilcock, E., Davies, G.A., 1993. A stochastic model to describe the operation of knitted mesh mist eliminators, computation of the separation efficiency. Institute of chemical Engineers 71, 282–294.

Helsr, T., Svendsen, H., 2007. Experimental Characterization of Pressure Drop in Dry Demisters at Low and Elevated Pressures. Chemical ngineering Research and Design 85 (A3), 377–385.

Knit wire Products- Knitted mesh mist eliminator – Technical Journal, world class reliability, quality and service, 2003. 1-22.

KOCH-OTTO YORK, 2002. Separation Technology, ‘‘Mist Elimination’’, 1-18.

Langmuir and Blodgett, K.B., 1946, ‘‘A mathematical investigation of water droplet trajectories’’, U.S. army Air Force Tech. Rep. 5418.

Monat, J., McNutty, K., Michelson, I., 1986. Accurate Evaluation of Chevron Mist Eliminators. Chem. Eng. Prog. 82, 32–39.

Payley, R.D., 1973. ‘‘Process application of knitted mesh eliminator’’, Chem. Process 33, 39.

Plant, W. and Fairs, G.L., Oct. 10, 1963. U.S. Patent No. 3,107,986.

Robison, P., 2003. Mist Separation. Hydrocarbon Engineering 82, 84.

Satsangee, P.D., 1948. Master Thesis, polytechnic Institute, Brooklyn.

Souders, M., Brown, G.G., 1934. Design of Fractionating Columns I. Entrainment and Capacity. Ind. Eng. Chem. 26, 98–103.

York, O.H., Popple, E., 1963. Wire mesh mist eliminators. Chem. Eng. Prog. 59, 45–50.

York, O.H., 1954. Performance of wire mesh demisters. Chem. Eng. Prog. 50, 421–425.

Ziebold, S.A., 2000. Demystifying mist eliminators selection. Chem. Eng. 107, 94–102.